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(71) Applicant: **The BOC Group plc**  
**Chertsey Road**  
**Windlesham**  
**Surrey GU20 6HJ (GB)**

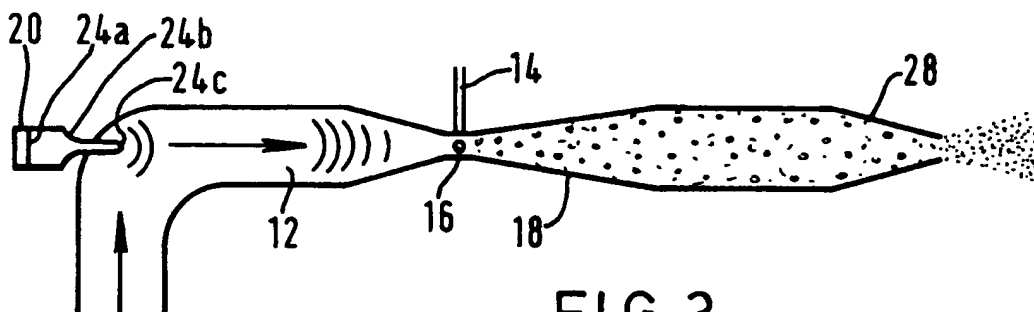
(72) Inventor: **Race, Michael Jack**  
**33 Coach Road,**  
**Greasbrough**  
**Rotherham,**  
**South Yorkshire, S61 4PU (GB)**  
Inventor: **Pickworth, Godfrey Brian**  
**Eversley,**  
**Valley Road,**  
**Hughenden Valley**  
**High Wycombe,**  
**Buckinghamshire, HP14 4PF (GB)**

(74) Representative: **Gough, Peter**  
**The BOC Group plc**  
**Chertsey Road**  
**Windlesham, Surrey GU20 6HJ (GB)**

(54) **Gas dissolution in liquids.**

(57) An apparatus (10) for dissolving gas in a liquid comprises a duct (12) for the passage of liquid therethrough, a gas supply (14) for introducing gas into said liquid and an ultrasound generator (20) for

generating ultrasound which is then used to produce "sonically induced cavitation" of any bubbles thereby to split said bubbles into smaller bubbles more easily dissolved in the liquid.



**FIG. 3.**

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The present invention relates to gas dissolution in liquids and relates particularly, but not exclusively, to the use of ultrasound to assist in the dissolution process.

Presently known methods of dissolving gas in a liquid include, for example, the well known BOC Group plc's VITOX<sup>TM</sup> system. This system comprises a venturi through which liquid to be oxygenated is passed and a plurality of small holes in the throat section through which oxygen is introduced into the liquid. The oxygen, in the form of bubbles, diffuses into the liquid downstream of the venturi thereby oxygenating the liquid.

It is well known that the smaller the bubbles are, the greater the speed and completeness of the dissolution process. However, presently known bubbling systems are predominantly mechanical devices all of which are unable to produce bubbles of a desirably small size without excessive, and hence uneconomic, power consumption.

It is an object of the present invention to reduce and possibly eliminating the problems of the above mentioned arrangements by providing an apparatus for dissolving a gas in a liquid which makes use of ultrasound to break up any gas bubbles thereby to produce bubbles of a size more suitable for the substantially complete dissolution of the gas contained therein into the liquid.

Accordingly, the present invention provides an apparatus for dissolving a gas in a liquid, the apparatus comprising:

a duct, for the passage of liquid therethrough;  
gas supply means, for introducing bubbles of gas into liquid to be passed through said duct;  
an ultrasound generating device for generating ultrasound; and

directing means for directing ultrasound into any liquid passing through said duct so as to produce "sonically induced cavitation" of any bubbles therein thereby to split said bubbles into smaller bubbles more easily dissolved in the liquid.

Preferably, the generating device is configured for generating ultrasound at or above the resonance frequency of the gas bubbles to be dissolved.

Conveniently the generating device comprises a piezoelectric device.

Advantageously, the directing means comprises a sonic horn so as to focus said ultrasound at a particular point within said duct.

Preferably the directing means is configured for directing the ultrasound substantially across the duct and across the path of liquid passing therethrough.

Alternatively, the directing means is configured for directing the ultrasound substantially along the duct and with, or against, the flow of any liquid passing therethrough.

The apparatus may further include turbulence generating means for generating turbulence within any fluid passing through the duct so as to further assist in the dissolution of gas within a fluid.

The ultrasonic generating means may be positioned for introducing ultrasound into the duct at a position upstream, downstream or coincident with the gas supply means.

Advantageously the apparatus further includes a diffuser for allowing the diffusion of the gas/liquid mixture thereby to facilitate the further dissolution of the gas bubbles in said liquid.

Additionally, there may be provided a venturi device within said duct for the passage of fluid therethrough.

Advantageously, the apparatus may further comprise an ejector or nozzle for introducing a mixture of gas/liquid from said duct into a large volume of liquid for the further dissolution of said gas therein.

The present invention will now be more particularly described by way of example only with reference to the following drawings, in which:

Figures 1 to 3 are cross-sectional views of three alternative arrangements of the present invention;

Figures 4 to 7 illustrate the collapse of a bubble when subjected to ultrasound in accordance with the present invention; and

Figure 8 is a table of bubble surface energy variation with size.

Referring now to the drawings in general, but particularly to Figure 1, the apparatus 10 for dissolving a gas in a liquid comprises a duct 12 for the passage of liquid therethrough, a gas supply means in the form of supply pipe 14 extending into the duct 12 or terminating at one or more holes 16 provided in the wall 18 thereof and an ultrasound generating device in the form of, for example, a piezoelectric transducer 20. Alternatively, the generating device could be a magnetostatic transducer, an electrostatic transducer or any one of a number of mechanical devices such as a Galton Whistle, a Hartmann Generator or a Janovski-Pohlman Whistle. A directing means formed either by the generating device 20 itself when correctly positioned or a focusing device shown at 24 is provided for ensuring the generated ultrasonic signal is directed towards a desired point within the duct. The focusing device sometimes referred to as a sonic horn 24 simply comprises a tapered member having a wider end 24a for receiving an ultrasonic signal and a tapered portion 24b for funneling the signal towards a narrower transmitting end 24c from which it is transmitted in a preferred direction.

The ultrasound generating device 20 is configured to generate ultrasound at or above the reso-

nant frequency of the gas bubbles to be dissolved. In practice, ultrasound frequencies in the range of 20-53kHz are sufficient to control the gas bubble size for most aqueous systems, however, the presence of salts or organics may require a different frequency. The particular frequency employed is selected to maximise the prime objective of mass transfer and this, in conjunction with the amplitude thereof, will be dependent upon the density, viscosity and temperature, for example, of the liquid, their state of motion and solids composition be it inert or organic in composition, together with consideration of the gas to liquid ratio required to achieve maximum mass transfer effect. In practice, selection of the correct frequency and amplitude could be a simple matter of trial and error until a particularly suitable choice is made.

The directing means 24 may be positioned for directing any produced ultrasound across or along the duct as shown in Figures 1 to 3 respectively and may be upstream, downstream or coincident with the gas supply means 14. A turbulence generator, shown schematically at 26, may be provided for inducing turbulence into the liquid so as to encourage further mixing of the bubbles with the liquid. The turbulence generator could be positioned anywhere in the duct 12 or could be formed by an output nozzle 28.

The inventive concept may be arranged in any one of a number of different ways some of which are shown in Figures 1 to 3. In Figure 1, a duct of substantially constant cross sectional area is provided with an upstream turbulence generator 26, a gas supply pipe 14 extending into the volume of liquid passing through the duct 12 and an ultrasound generator 20 positioned for directing ultrasound across the duct downstream of the point at which gas is introduced. A nozzle 28 at the output end of the duct may be conventional or could be provided with a swirl inducer (not shown). Indeed, a swirl inducer may be provided at any point along the duct. Figure 2 illustrates an arrangement where a venturi device 17 forms part of the duct 12 and gas is introduced at the throat of the venturi and upstream of the ultrasound generator 20 which is arranged to direct ultrasound across the duct. Figure 3 illustrates a still further alternative similar to that shown in Figure 2 except that the ultrasound generator 20 is positioned upstream of the venturi 17 and acts to direct ultrasound substantially along the duct rather than thereacross. Other arrangements not illustrated herein will present themselves to the reader of this application and hence the present invention is in no way limited to the illustrated embodiments. It is preferable to have the ultrasound generator acting as close to the exit of the duct as possible, thereby to minimise the possibility of bubble coalescence

before ejection.

It has been demonstrated by A T S Pandit and J F Davidson "Bubble Break-up in Turbulent Flow" that the energy requirement to change the bubble size matches the change in energy of the surface, ie, surface tension increase. In systems where the liquid is water viscosity effects are negligible. Ultrasonics provide an alternative energy source which, if used effectively, gives the order of magnitude reduction in bubble size necessary to effect a significant change in the mass transfer capability of the system. Bubble size produced in a VITOX<sup>TM</sup> venturi is of the order 1.5-2.5mm diameter at the throat conditions. The application of ultrasound provides a mechanism to reduce this by one order of magnitude (approximately). If by suitable location of the venturi, the resultant downstream pipework equipment were configured such that under dynamic conditions a pressure gradient existed, such that the bubbles are subjected to increasing pressure, then they will reduce in size. At the VITOX<sup>TM</sup> nozzle the extra shear energy would encourage further bubble disintegration, particularly the larger bubbles formed through coalescence, resulting in the issue to the bulk tank of a two phase stream in which the average bubble would be about 0.15-0.25mm in diameter. If the mixing arrangements are suitable, then bubbles of this size will not exhibit sufficient buoyancy to escape to the surface and thus will rapidly dissolve. This tank effect is enhanced by the use of swirl ejector nozzles.

Any oxygen supply pressure can be accommodated by correct design of the system hydraulics. Thus, the ultrasonics would work equally well with subatmospheric supply in self aspirating devices, to pressurised systems, eg, submersible units.

The device can be adjusted to the physical properties which dictate the various physical characteristics of the ultrasonic mechanism, be applied to most gas/liquid contacting systems, eg, ozone and water, carbon dioxide/water (although CO<sub>2</sub> is less favourable due to its sound attenuation). Air/water systems behave in a similar manner to oxygen water systems. Various patents cover processes for dissolving gases into liquid media, each requiring external energy application to create movement of the liquid, typically a pump, combinations of pressurised liquid flow inducing shear of bubbles aiding dissolution of the introduced gas into the liquid stream. Thus use of ultrasound in all of the above processes does improve their performance in terms of mass transfer of gas into solution.

In operation, liquid such as for example water or sewage is passed along duct 14 in which a gas, such as for example Oxygen, is bubbled. These bubbles are acted upon by the effect of the ul-

trasound so as to cause the breakup thereof. Breakup is best illustrated by reference to Figures 4 to 7 which illustrate one bubble as it passes through the zone in which the ultrasound is contained. An initially large bubble 30 is subjected to acoustic cavitation, that is to say the growth and collapse of the bubble due to the energy inputted from the ultrasound. In certain circumstances, bubbles are known to expand up to twice their original size and then contract down to less than one half their original size. This breakup can be achieved by using ultrasound to excite the bubbles 30 beyond their resonant frequency and thereby cause the bubble wall to be accelerated non-uniformly such that the wall forms a liquid jet which travels across the bubble and shatters it into a number of smaller bubbles during contraction as illustrated in Figures 6 and 7. Clearly, the more irregular the bubble shape the easier it will be to ensure breakup occurs as each irregular portion will exhibit a natural tendency to split from its neighbour. It has been found that elongate bubbles are more easily broken up than perfect spheres. The sound pressure exerted on the bubbles would roughly translate to about 110 decibels (dB) if it could be heard. The turbulence inducers or swirl generators help to produce further mixing of the liquid/gas combination in a manner already well known by those skilled in the art and therefore not described herein. Finally, the liquid/gas mixture is ejected into a bulk of liquid. A reduction in the bubble size to within the range described herein substantially reduces the buoyancy and hence the ability of the bubble to rise to the surface before complete dissolution takes place.

#### Claims

1. An apparatus (10) for dissolving a gas in a liquid, comprised by:  
a duct (12), for the passage of liquid therethrough;  
gas supply means (14), for introducing bubbles (30) of gas into liquid to be passed through said duct;  
an ultrasound generating device (20) for generating ultrasound; and  
directing means (20) for directing ultrasound into any liquid passing through said duct (12) so as to produce "sonically induced cavitation" of any bubbles (30) therein thereby to split said bubbles into smaller bubbles more easily dissolved in the liquid.
2. An apparatus (10) as claimed in Claim 1 characterised in that said generating device (20) is configured for generating ultrasound at or above the resonance frequency of the gas bubbles (30) to be dissolved.
3. An apparatus as claimed in Claim 1 or Claim 2 characterised in that the generating device (20) comprises a piezoelectric device.
4. An apparatus as claimed in any one of the preceding claims characterised in that the directing means (20) comprises a sonic horn (24b) so as to focus said ultrasound at a particular point within said duct.
5. An apparatus as claimed in any one of the preceding claims characterised in that the directing means is configured for directing the ultrasound substantially across the duct and across the path of liquid passing therethrough.
6. An apparatus (10) as claimed in any one of Claims 1 to 4 characterised in that the directing means is configured for directing the ultrasound substantially along the duct (18) and with, or against, the flow of any liquid passing therethrough.
7. An apparatus as claimed in any one of the preceding claims characterised by turbulence generating means (26) for generating turbulence within any fluid passing through the duct (18) so as to further assist in the dissolution of gas within a fluid.
8. An apparatus as claimed in any one of Claims 1 to 7 characterised in that said ultrasonic generating means (20) is positioned for introducing ultrasound into the duct at a position upstream, downstream or coincident with the gas supply means.
9. An apparatus as claimed in any one of the preceding claims 1 to 8 characterised by a diffuser for allowing the diffusion of the gas/liquid mixture thereby to facilitate the further dissolution of the gas bubbles in said liquid.
10. An apparatus as claimed in any one of the Claims 1 to 9 characterised by a venturi device within said duct for the passage of fluid therethrough.
11. An apparatus as claimed in any one of Claims 1 to 10 characterised by an ejector or nozzle (28) for introducing a mixture of gas/liquid from said duct (18) into a large volume of liquid for the further dissolution of said gas therein.

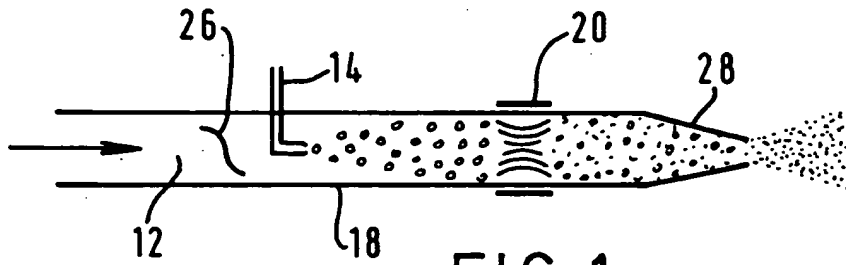


FIG. 1.

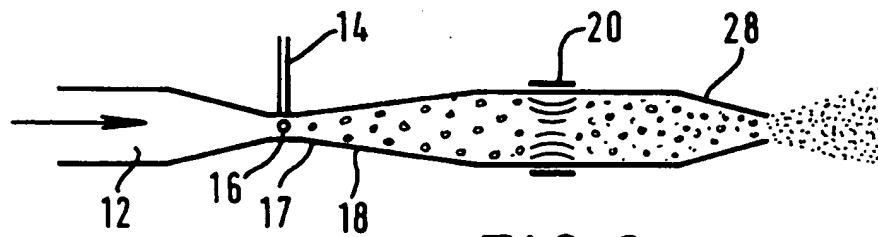


FIG. 2.

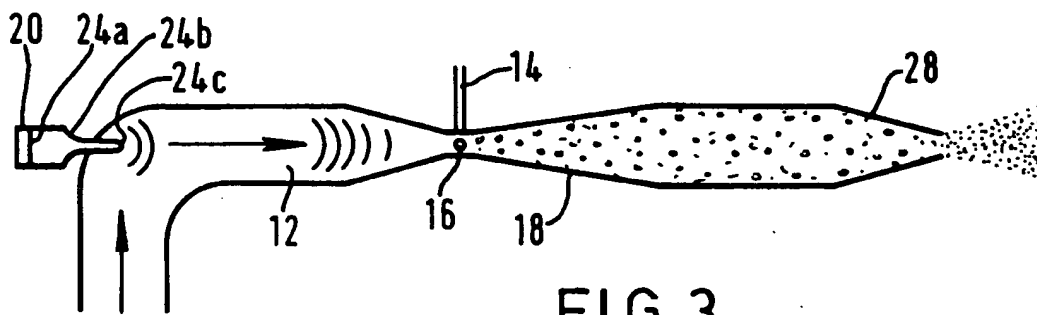
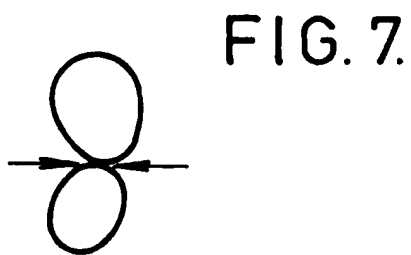
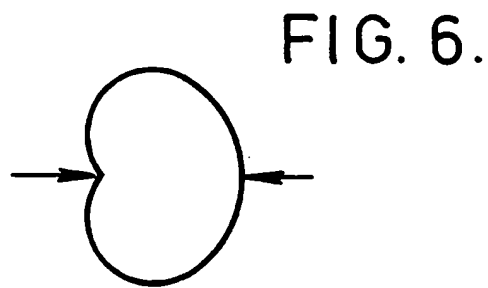
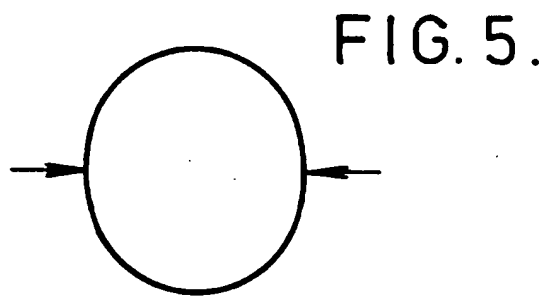
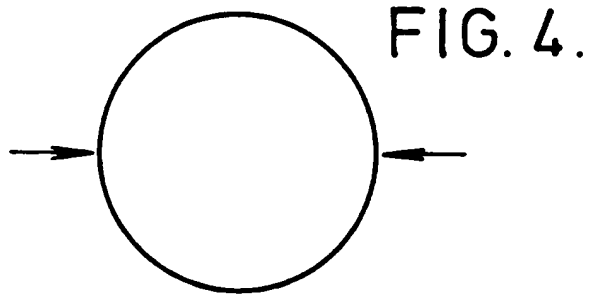


FIG. 3.



## FIG. 8.

## Bubble Surface Energy Variation With Size

GBP/18/1/94

Gas Volum		28.12 m.hr		1500 kg.d	
				Surface Tension @ 10-1 0.074	
N.m	Bubble	Surface	Surface	Bubble	Bubble
Resonant	Diameter	Area	Energy	Number	Energy
Frequency	mm	m <sup>2</sup>	N.m	s	N.m.s
Hz					watts
646	10	3.14E-04	2.32E-05	14920	0.347
680	9.5	2.84E-04	2.10E-05	17402	0.365
718	9	2.54E-04	1.88E-05	20467	0.385
760	8.5	2.27E-04	1.68E-05	24295	0.408
808	8	2.01E-04	1.49E-05	29141	0.434
861	7.5	1.77E-04	1.31E-05	35366	0.462
923	7	1.54E-04	1.14E-05	43499	0.496
994	6.5	1.33E-04	9.82E-06	54329	0.534
1077	6	1.13E-04	8.37E-06	69075	0.578
1175	5.5	9.50E-05	7.03E-06	89678	0.631
1292	5	7.85E-05	5.81E-06	119361	0.694
1436	4.5	6.36E-05	4.71E-06	163733	0.771
1615	4	5.03E-05	3.72E-06	233128	0.867
1846	3.5	3.85E-05	2.85E-06	347992	0.991
2153	3	2.83E-05	2.09E-06	552599	1.156
2584	2.5	1.96E-05	1.45E-06	954890	1.387
3230	2	1.26E-05	9.30E-07	1865020	1.734
4307	1.5	7.07E-06	5.23E-07	4420789	2.312
6460	1	3.14E-06	2.32E-07	14920162	3.469
7178	0.9	2.54E-06	1.88E-07	20466615	3.854
8075	0.8	2.01E-06	1.49E-07	29140942	4.336
9229	0.7	1.54E-06	1.14E-07	43499016	4.955
10767	0.6	1.13E-06	8.37E-08	69074826	5.781



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## EUROPEAN SEARCH REPORT

Application Number  
EP 95 30 1776

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	US-A-5 123 433 (D.E.FRIDSMA ET AL) * the whole document * ---	1-11	B01F11/02 B01F3/04
Y	SOVIET PATENTS ABSTRACTS Section Ch, Week 9241, 25 November 1992 Derwent Publications Ltd., London, GB; Class D15, AN 92-338686 & SU-A-1 690 837 (GORKI ENG CONS INST) 15 November 1991 * abstract * ---	1-11	
Y	PATENT ABSTRACTS OF JAPAN vol. 6, no. 44 (C-95) (922) 19 March 1982 & JP-A-56 161 824 (CHIYODA KAKO KENSETSU KK) 12 December 1981 * abstract * ---	1-11	
A	DE-A-43 05 660 (S.MAYER) * claims * ---	1	
A	US-A-4 433 916 (M.N.HALL) * claims; figure 6 * -----	1	TECHNICAL FIELDS SEARCHED (Int.Cl.6)  B01F B01J C02F B01D B08B
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 30 May 1995	Examiner Cordero Alvarez, M
<b>CATEGORY OF CITED DOCUMENTS</b>  X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document  T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons  & : member of the same patent family, corresponding document			